CW VELOCITY SELECTION BY DYE LASER OPTICAL PUMPING*

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A technique is presented by which a thermal atomic beam of sodium was prepared with one narrow velocity component of the beam selectively pumped to a particular ground state hyperfine level, and the remainder of the velocity components pumped into another ground state level. The technique uses a single cw dye laser.

The recent development of highly stable tunable dye lasers provides the means for many novel spectroscopic techniques [1–4]. In this letter we would like to describe a technique by which we use a single dye laser to selectively pump a particular velocity component of a thermal atomic beam of sodium atoms into a particular hyperfine level while pumping the atoms from the remainder of the velocity profile into another ground state level.

The experimental apparatus consists of a cw dye laser which operates in a single mode and is stable to within 3 MHz over 10 sec. The atomic system is sodium in a conventional thermal atomic beam. Both the laser and the atomic beam are described in a previous publication [3]. No mechanical velocity selection is used, and magnetic fields are negligible.

The D_2 line which is used for the experiment has energy levels as pictured in fig. 1. The selection rules are $\Delta F = 0, \pm 1$ so that transitions $F = 1 \rightarrow 3$ and $F = 2 \rightarrow 0$ are forbidden. If a laser is resonant between any two levels there will always be another ground state level to which the system can be pumped except for the $F = 2 \rightarrow 3$ and $F = 1 \rightarrow 0$ transitions. These two resonances act as 2-level atoms whereas all other resonances have 3 levels and the population can be pumped by the laser into the non-resonant third level.

The procedure in the experiment is to cross the atomic beam three times by portions of the laser beam. The first two times the atomic beam ground state populations are manipulated and the third time the laser acts as a probe. The laser needs to be tuned to only one frequency. Subsequently the angle of intersection of the laser and the atomic beams defines the apparent Doppler shifted frequency to the atoms. Fig. 2 illustrates this.

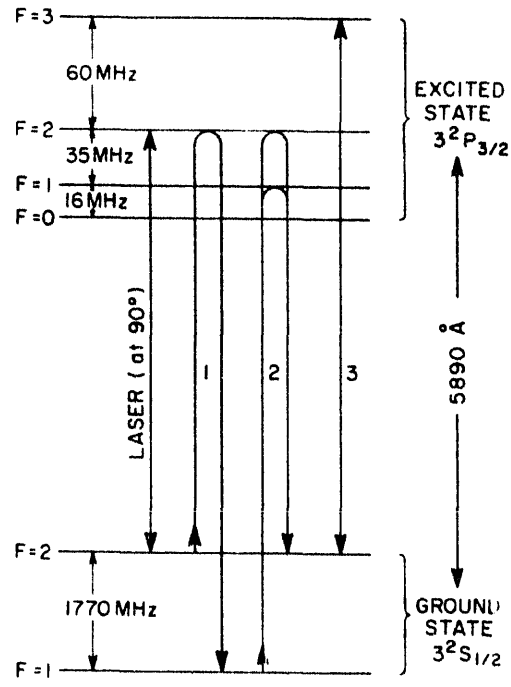

Fig. 1. Energy levels contributing to the Na D_2 hyperfine structure. Note that the drawing is not to scale.

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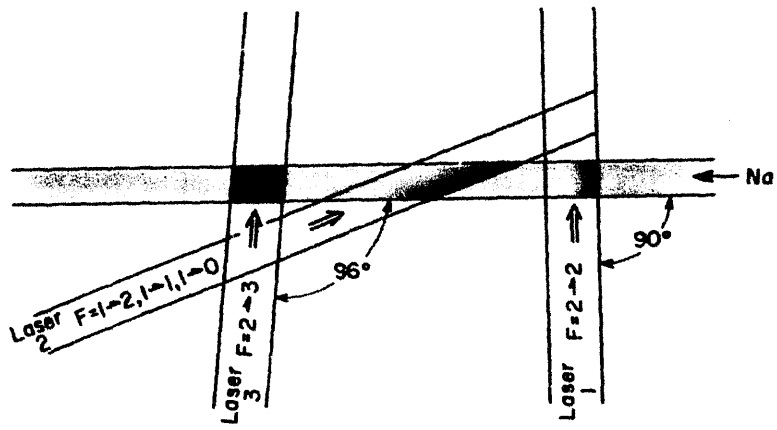

Fig. 2. Atomic beam – laser beam arrangement. All three laser beams are from the same laser reflected from appropriate mirrors. The shading in the region of intersection represents the fluorescence.

The single mode laser is first tuned to the $F = 2 \rightarrow$ transition when the laser and atomic beams are at right angles. The effect of laser beam 1 is to pump the population of the $F = 2$ ground state into the $F = 1$ ground state by way of spontaneous emission from the $F = 2$ excited state. After the atoms leave the first illuminated region the population is entirely in the $F = 1$ ground state.

Laser beam 2 crosses the atomic beam at a very large angle. The atoms see the laser frequency upshifted by an amount proportional to the atomic velocity. For three closely spaced velocities the atoms are resonant with the $F = 1 \rightarrow 2$, $F = 1 \rightarrow 1$, $F = 1 \rightarrow 0$ transitions. For two of these three velocities the atoms are optically pumped back into the $F = 2$ ground state by spontaneous emission from the $F = 2$ and $F = 1$ excited states.

After these two interactions, the velocity distributions for the two ground states appear as in fig. 3 for an oven temperature of 400°C and for an angle of 180° between laser beam 2 and the atomic beam. The $F = 2$ ground state is populated entirely by atoms with a velocity of $1.04 \pm 0.02 \times 10^5$ cm/sec. Laser beam 3 can now probe the velocity selected atomic beam. By a suitable choice of intersection angle between the atomic beam and laser beam 3, the selected atoms can be Doppler shifted into resonance on any one of the following transitions; $F = 2 \rightarrow 1$, $F = 2 \rightarrow 2$, $F = 2 \rightarrow 3$.

It is feasible to measure atomic decay times and optical pumping times by observing the decay of fluorescence downstream from the third interaction region. In addition, atoms can be given precise optical pulses by passing them through a known cw light field and optical nutation phenomena can be studied.

The advantage of this method over conventional velocity selectors are:

1) The velocity selection is continuous and there is no loss of atomic flux.

2) The probe and the pumping beams are tapped off of a single laser operating at a single frequency.

3) The range of velocities selected and the center

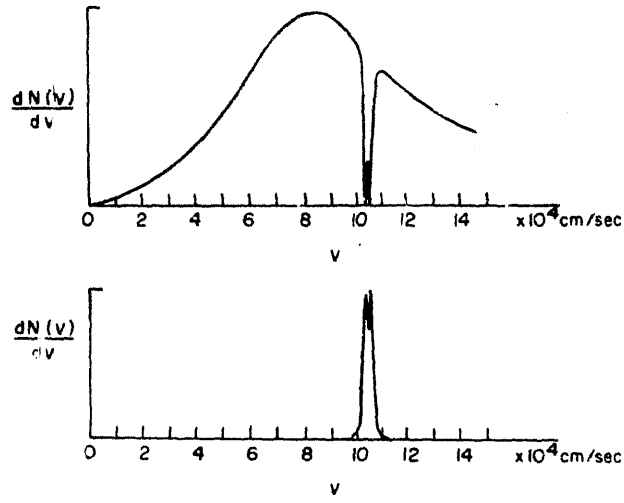

Fig. 3. (a) The velocity distribution of atoms in the $F = 1$ ground state after pumping by laser beams 1 & 2. The hole is made up of two separate very closely spaced velocity components corresponding to the $F = 1 \rightarrow 2$ & $1 \rightarrow 1$ transitions. (b) The velocity distribution of atoms in the $F = 2$ ground state after pumping. For the same reason, we again have two closely spaced components.

velocity are variable independently. The angle which laser beam 2 makes with the atomic beam determines the center of the velocity band. The convergence of the laser beam determines the breadth of the velocity band.

The experimental evidence for this method can be seen with the unaided eye since the scattered intensities are in the nanowatt/cm^2 range. The atomic beam has collimating apertures 0.5 mm in diameter and 25 cm apart. This produces a Doppler spread of less than 10 MHz transverse to the beam. The natural linewidth is also 10 MHz. The laser beams are apertured so that the interaction regions 1 and 3 are 1 mm in length.

With the first laser beam intensity at about 30 mW/cm the optical pumping is visible as an illuminated band extending about 0.2 mm downstream at the front of the interaction region. With the oven temperature at 400°C this means that optical pumping is achieved in a few hundred nanoseconds. The downstream edge of the interaction region is dark since all of the atoms are optically pumped by the time they arrive there.

With laser beam 3 making an angle of about 96° with the atomic beam, the two-level transition $F = 2 \rightarrow 3$ is shifted into resonance. Optical pumping does not take place there and the entire interaction region is illuminated by resonance fluorescence. When laser beam 2 is moved off of intersection with the atomic beam, the third interaction region dims considerably as expected.

The velocity resolution in this experiment is determined by the closeness of the excited state levels $F = 2$ and $F = 1$, by power broadening which at these intensities is of the order of the natural linewidth, and by the laser beam collimation. The atomic beam is so diffuse that collisions which would mix ground state populations are rare.

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